BRICK MASONRY CULVERTS

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ABSTRACT An account is given of the design and construction aspects of brick masonry arched culverts which have been provided in series to cater to the requirements of water-way under the approach road leading to a bridge serving the intake structure for water supply to a Refinery Plant. A comparision is also made with an alternative proposal of reinforced concrete box culverts. By using brick masonry arched culverts the favourable strength characteristics were fully exploited since the geometric shape went in favour of adopting brick masonry. These culverts provided aesthetically pleasing look by the side of the road embankment.

1. INTRODUCTION

Brick work had been for centuries a material of construction for buildings, bridges and irrigation works wherein its properties had been exploited fully for various styles and forms. Whereas, it had been in use for structural requirements, its use for aesthetic purpose was also very common.

Recently with the adoption of concrete, use of brick work has found a set back. Out of enthusiasm and because of its mould-ability engineers prefer concrete as a construction medium. Concrete and reinforced concrete have become the primary materials of construction, thereby leaving bricks to be used purely as an architectural material.

An engineer must make a judicious selection of materials for construction. Brick work has favourable characterstics for its use as a structural material in addition to being an effective cladding material with good thermal and accoustic properties. Where compression is predominant, un-reinforced brick work should be the only choice. Keeping this in view, the engineer should adopt a structural form for exploiting the favourable properties of brick work. Some of the important properties which should be considered while designing brick-work are narrated below :

a) Brick work loaded in uniform compression usually fails by the development of tension cracks parallel to loading. The reason for such a behaviour is that tension develops perpendicular to the main compression. The secondary tensile stresses that lead to splitting failure of the brickwork result from the restrained deformation of the bed joint mortar.

b) The compressive strength of the brickwork varies approximately as square root of the nominal brick crushing strength and approximately third or fourth root of the cube strength of the mortar.

c) For favourable strength properties of the brickwork, workmanship is very important. It has been found that an improper workmanship can lead to reduction in strength by 25 to 35 percent. The controlling factor is joint thickness. Thicker joints tend to reduce the strength. Fig.1 shows the effect of joint thickness on brick-work strength.

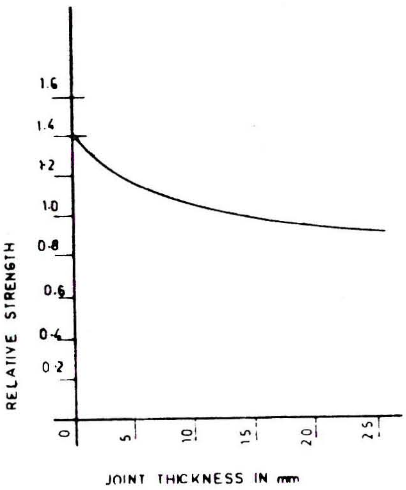


FIG.1 JOINT THICKNESS V STRENGTH

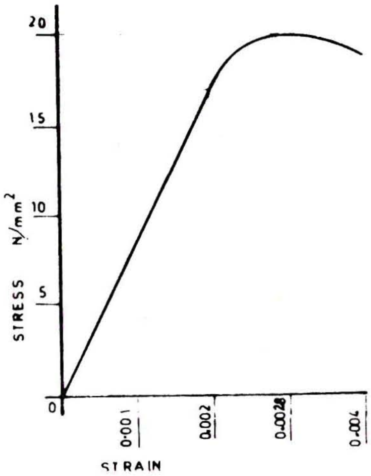


FIG.2 STRESS V STRAIN

d) Stress-strain relationship of the brickwork is generally considered as linear within elastic limits. The tests indicate it as shown in Fig.2. Under service conditions brickwork is stressed upto only a fraction of its ultimate strength and, therefore, the assumption of linear stress-strain curve is in order.

Though the young's modulus is variable for various specimens, the approximate value is given by $E = 700\ \sigma_c$

Where σ_c is the crushing strength of the masonry. For estimating long term deformations, 1/2 to 1/3 of the above value should be adopted.

2. THEORY OF BRICK-ARCH

Brick arch is one of the oldest and most interesting structural form. Since the arch is basically required to resist compression, this is adaptable to brick masonry construction. It is one of the most attractive structural forms. This form in brick masonry has been used in floors, foundations, super structures of buildings, aquaducts and bridges. Development of dome had been from the vault which in turn had derived itself from the arch.

The downward load on the arch creates compression thrusts in the arch-span, which pushes the masonry units against each other and compresses them, and in turn the arch thrusts against the abutments. In addition, there are moments along the span, shear perpendicular to axis in each section and forces in the lateral direction.

On review of the strength properties of brick masonry stated earlier in relation to the arch action, the lateral splitting due to secondary tensile stresses is resisted by the overburden. Also care should be taken to generate compressive stresses in relation to which the secondary tensile stresses will be nominal and help avoid splitting. The joints on the intrados will be narrow and as such their thickness is favourable to the strength. In addition, the wedging action increases bond between the brick and the mortar, thereby enhancing the strength characterstics of the brickwork.

Brick arches are fixed arches. The following conditions must be satisfied for pure arch action.

a) the span length should be constant

b) the end elevations must remain unchanged

c) the inclination of the skewback must be fixed.

Violation of any of the above conditions due either to sliding, rotation or settlement can cause generation of critical stresses leading to failure. Keeping these in view the failure may take place in following three ways.

a) By rotation of one section of the arch about the edge of a joint :

If the equilibrium polygon (line of thrust) lies entirely within the middle of the section, no rotation of a section about the joint or no tensile stresses in intrados or extrados occurs.

b) By sliding of one section of the arch on another or on the skewback :

The coefficient of friction is of the order of 0.50 without considering the additional resistance to sliding resulting from bond between mortar and masonry units. This friction corresponds to an angle of friction of 27 deg. approximately. If the line of resistance, the arch makes with the normal to the joint between arch sections, is less than the angle of friction, the arch is stable against sliding.

c) By crushing of the masonry :

Unit stress should be well within the permissible limits to avoid crushing.

Brick arches are normally sized by thumb rules and then verified by one or more methods. There are two theories for the stability of the masonry arch.

a) Theory of line of thrust.

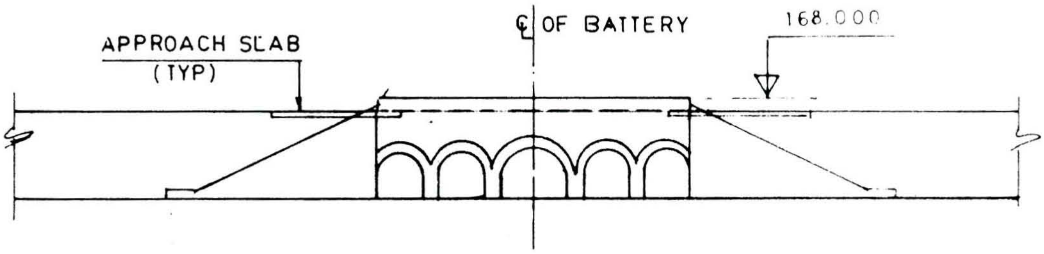
b) Theory of Elastic deformation.

The line of thrust theory considers the stability of the arch ring depending upon the friction and reactions between voussoirs. This theory is applicable to symmetrical masonry arches loaded uniformly over the entire span or subjected to symmetrically placed concentrated loads. For these arches the line of resistance which is the line connecting the points of application of the resultant forces transmitted to each voussoir, is required to fall within middle third of the arch section so that neither the intrados nor the extrados are in tension. Prof. Pippard stated that the middle third rule was unduly pessimistic and suggested the use of middle half rule. He has also found that the thrust could pass not just outside the middle half, but outside the arch ring without the arch collapsing. In such a case the tension can cause minor cracking without collapse of the arch.

The elastic theory considers the arch as a curved beam and its stability depends on internal stresses. For arches subjected to non-symmetrical loading, which may develop tensile stresses in the arch, elastic theory provides a more accurate method of analysis than the line of thrust theory.

3. BRICK ARCH CULVERTS

For a Refinery Project the water supply scheme comprises of an intake well located in a major perennial river a few kilometers away from the plant. The intake well is approachable from a highway through an approach road over embankment and then by a bridge. A waterway has been provided through the embankment using 21 batteries each consisting of 5 arches in brick masonry to facilitate passage of water during monsoon when the river is in spate. The construction was done in the year 1979. Fig (3) and (4) shows a typical detail of brick arch culverts (single battery) adopted for the project.



ELEVATION

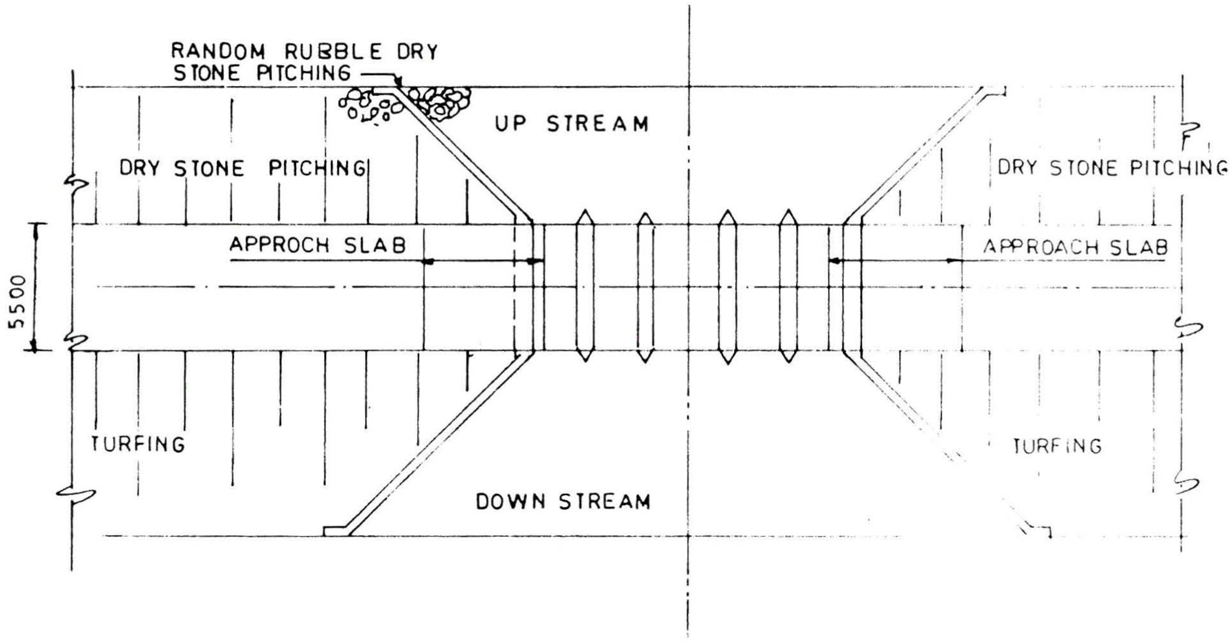
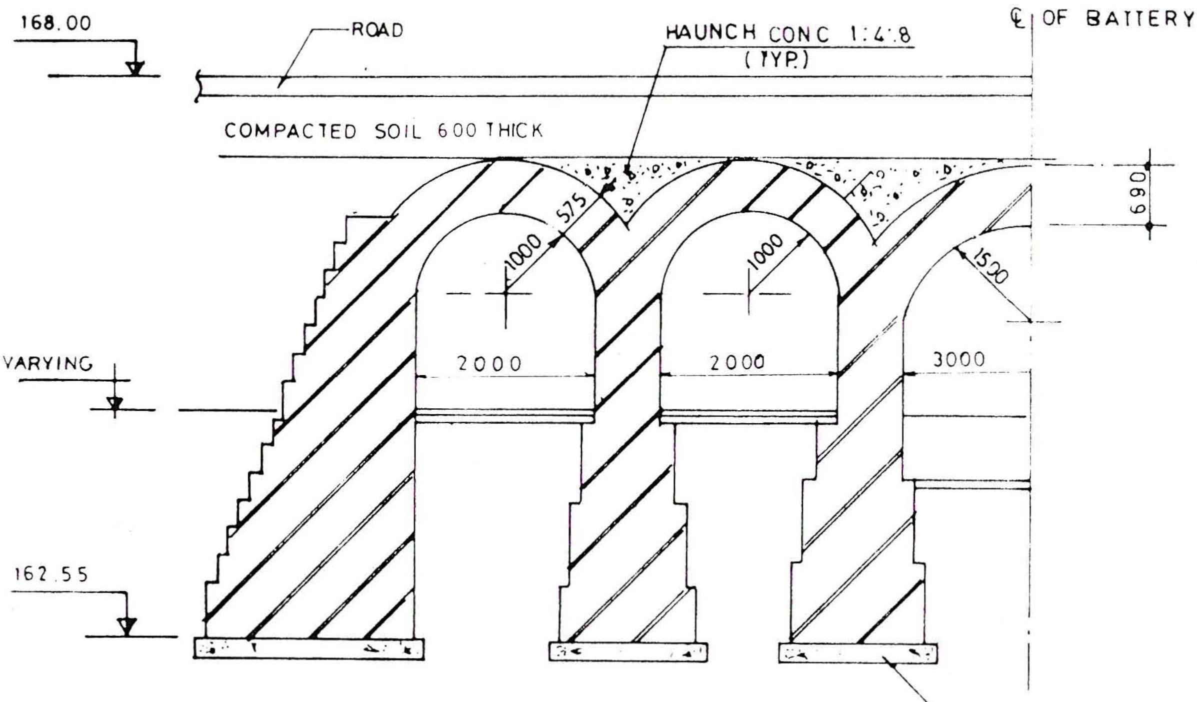
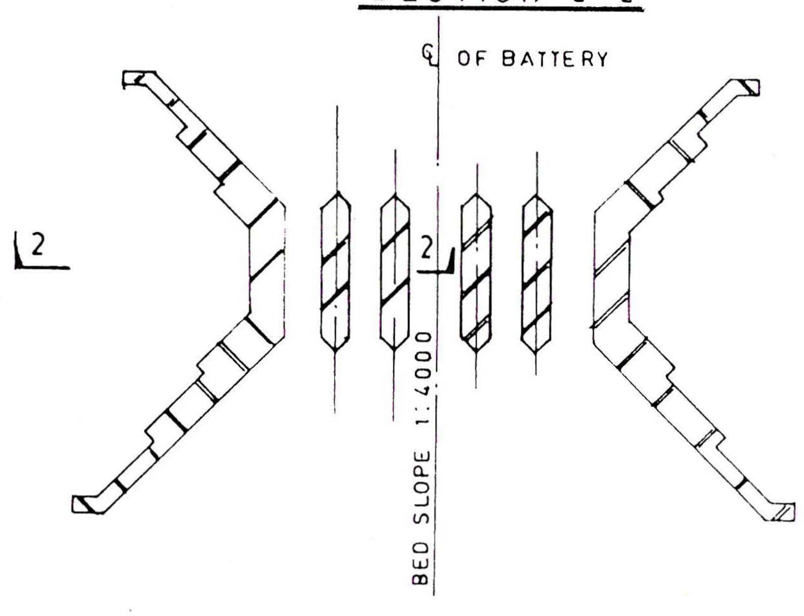


FIG.3. TYPICAL PLAN OF ONE BATTERY OF BRICK ARCH CULVERT



SECTION-2-2



FOUNDATION PLAN

FIG.4. DETAIL OF CULVERTS

The semicircular shape of the arch was adopted for ease in construction and to reduce the thrust in the abutments. Also this helps to provide a passage to bullock-carts during fare weather so that a high rise arch was the only choice in view of a low embankment and preference to have a minimum cushion of 600 mm above the extrados. The shallow height and the requirement of head - room dictated the span adopted. The brick-arch to a concrete box-culvert was preferred in view of the easy availability of indigenous supplies of bricks and local masons. For reinforced concrete culverts, skilled labour was required and the transportation of the material from long distances was troublesome. Also concrete construction would have taken more time in view of requirement of bending/binding of bars, longer time for striking of forms etc. Aesthetically the arches were considered to be more beautiful compared to concrete construction and the brick arches suited well considering the ancient construction styles seen in the town located nearby.

Before designing it was essential to fix the thickness of the arches based on empirical relation. The following empirical formula in F.P.S. units was used which is independent of the nature of loading.

Trautwine : D (depth of Section) $= 0.27 + 0.33 \sqrt{\left(\frac{S}{2} + R \right)}$

Where S = Span

R = Radius

Substituting the Values in above formula, we get

D = 250mm for span of 2000mm

D = 360mm for span of 3000mm

Finally a thickness of 575 mm for 2.0 M arch and 690 mm for 3.0 M arch was adopted keeping in view the vehicular loads.

The mortar used was of proportion 1:3 (1 cement : 3 sand)

The design was done using theory of elastic deformation and adopting class B Vehicular loading of IRC (Indian Roads Congress) as shown in Fig. 5. Since the approach road was proposed to be used for private use only, the load indicated by arrow 'A' in Fig. 5 was considered for design. The force parameters coming on the crown and the abutment of the arches as computed based on above loads are shown below in Table-I.

Table - I

Clear Span (mm)	At Springing			At Crown		
	V (N)	H (N)	M (N-M)	V (N)	H (N)	M (N-M)
2000	57	37	10	0	37	6
3000	85	52	18	0	52	20

Where V = Vertical reaction

H = Horizontal thrust

M = Bending - moment

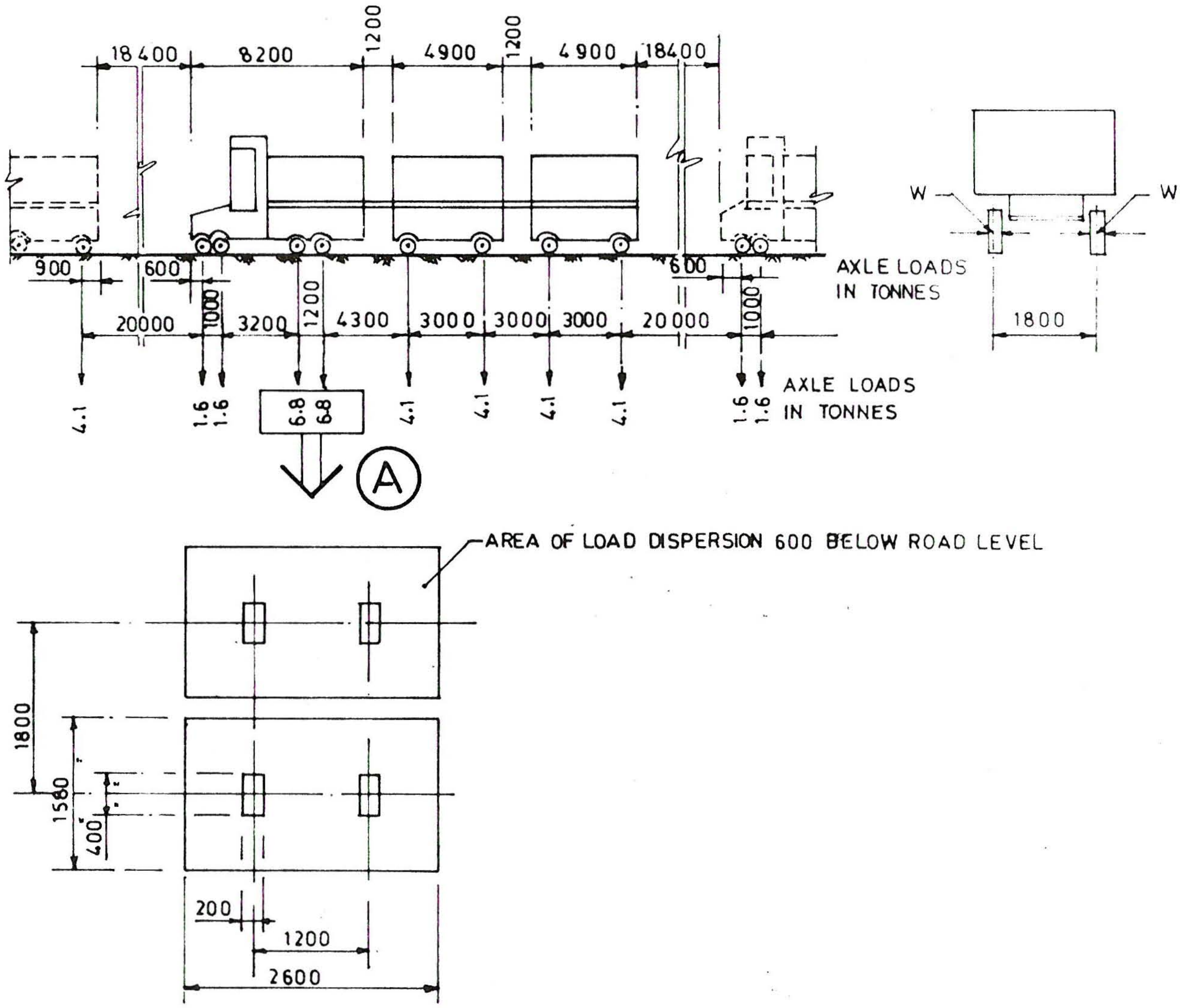


FIG.5 DETAIL OF IRC LOADING

These forces generate low stresses without any tension anywhere in the arches. Since the compressive stresses are low, the splitting secondary tensile stresses will be insignificant. However, if the braking effect of the vehicle is considered the tensile stresses at the crown level will be of the order of 0.12 N/mm^2 (1.2 Kg/cm^2) for 2.0 m arch and 0.28 N/mm^2 (2.8 Kg/cm^2) for 3.0 m arch. These tensile stresses have been allowed in the arches considering the recommendation of Prof. Pippard. The effect of temperature changes being gradual in the area was not considered.

In order to work out the economics the cost of the battery of brick arch culverts was compared with that of a battery of box culverts in reinforced cement concrete. It was found that the brick arch culverts worked out to be cheaper by about 20 percent over the designed RCC Box culverts. In addition to economy brick work culverts afforded speed, ease in construction and pleasing visual environment.

4. CONCLUSION

By adopting brick arch construction more commonly than is being used and by extensive study of structural behaviour of such arches, masonry

designers will be able to achieve more confidence in design tolerances and thereby achieve economy and keep alive the age old style of construction which definitely has a wide edge over reinforced concrete construction practices.

5. ACKNOWLEDGEMENT

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